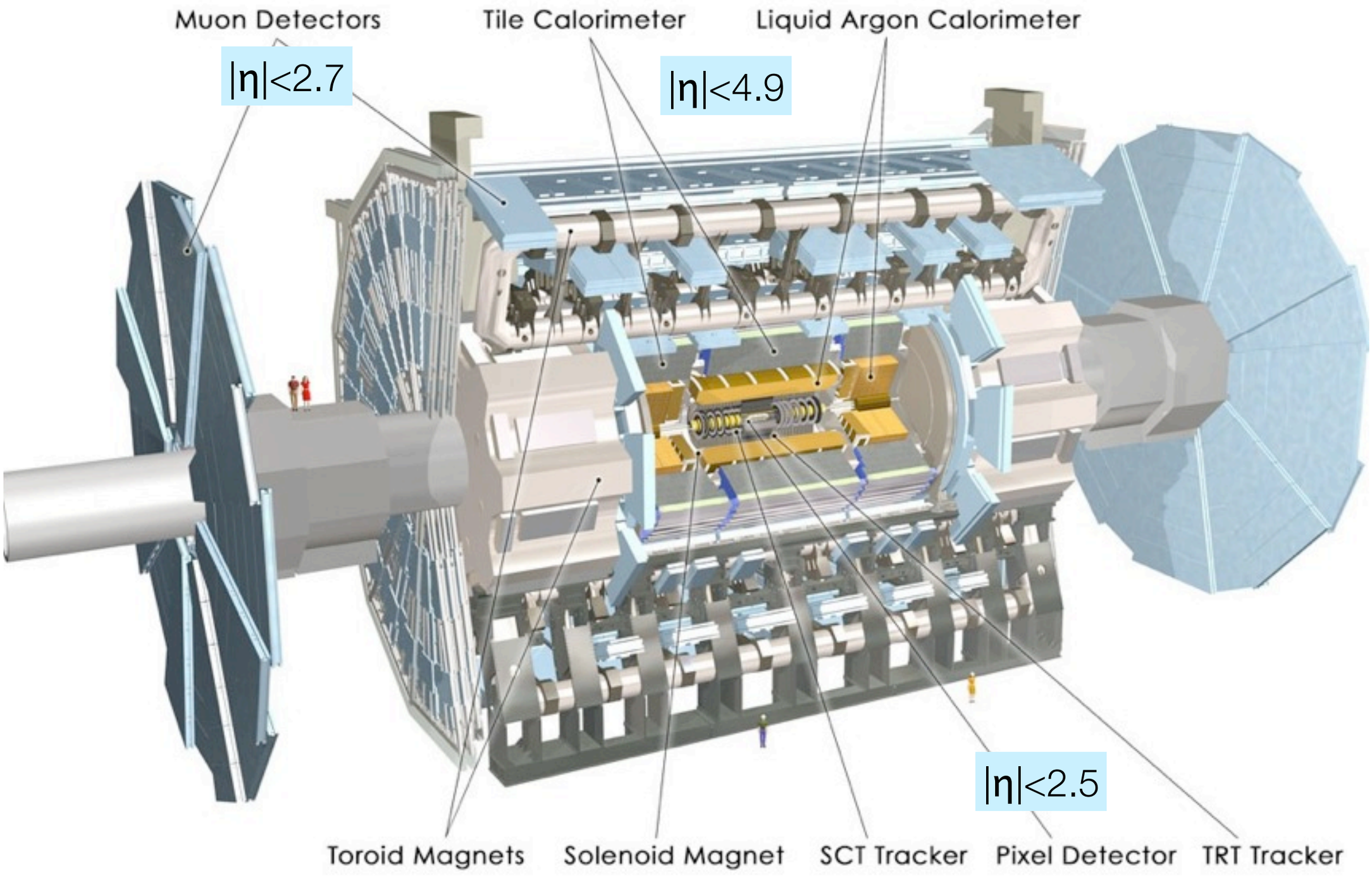
Quarkonia and Vector Bosons measured with the ATLAS detector at the LHC

Peter Steinberg, for the ATLAS Collaboration
Brookhaven National Laboratory
June 15, 2011
BNL Quarkonia Workshop

J/psi and Z results:	**Phys.Lett. B697:294-312,2011**
W results:	**http://cdsweb.cern.ch/record/1353227**

Special thanks to Helio Takai & Rikard Sandstrom

The ATLAS Detector



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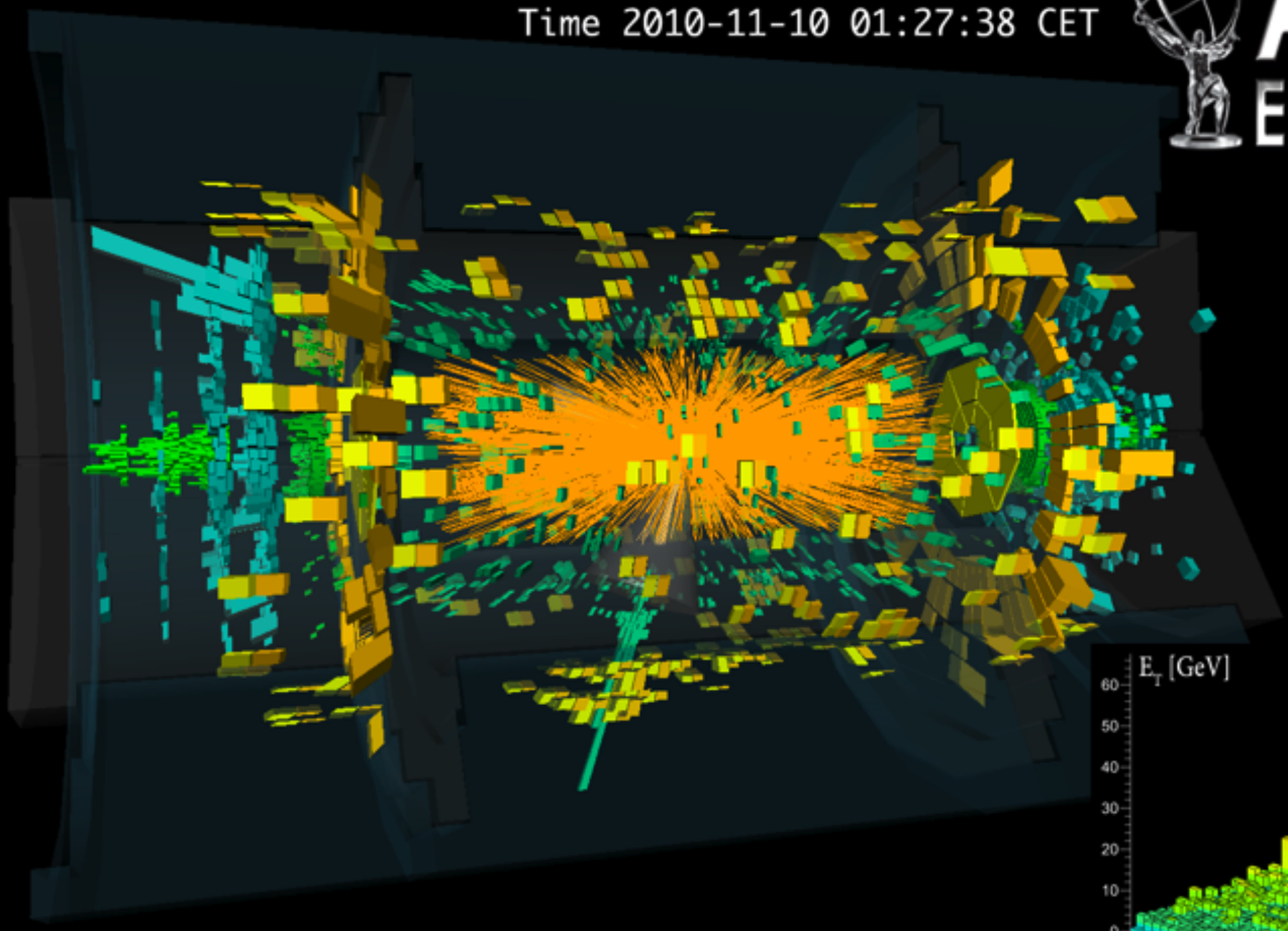
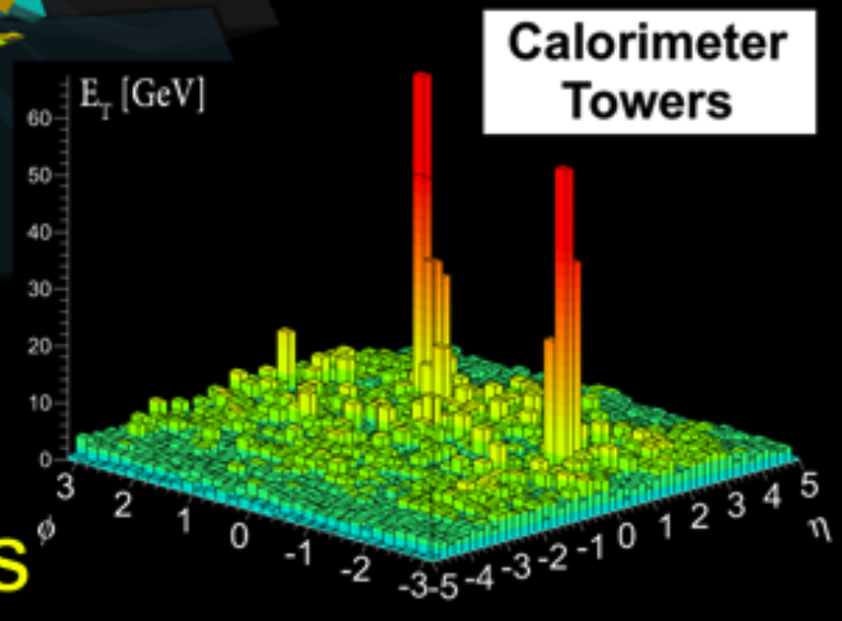
Run 168875, Event 1577540
Time 2010-11-10 01:27:38 CET

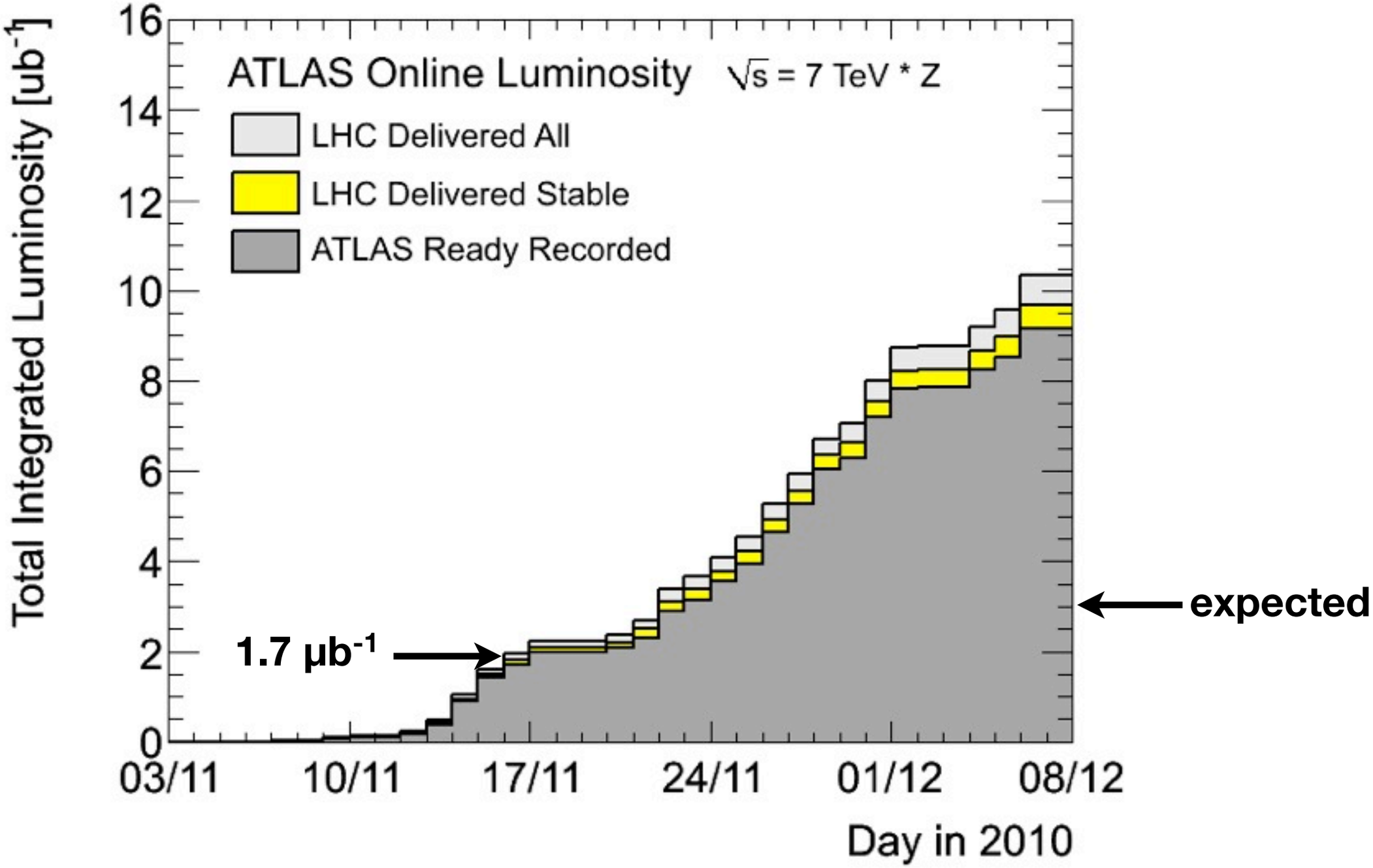
ATLAS EXPERIMENT





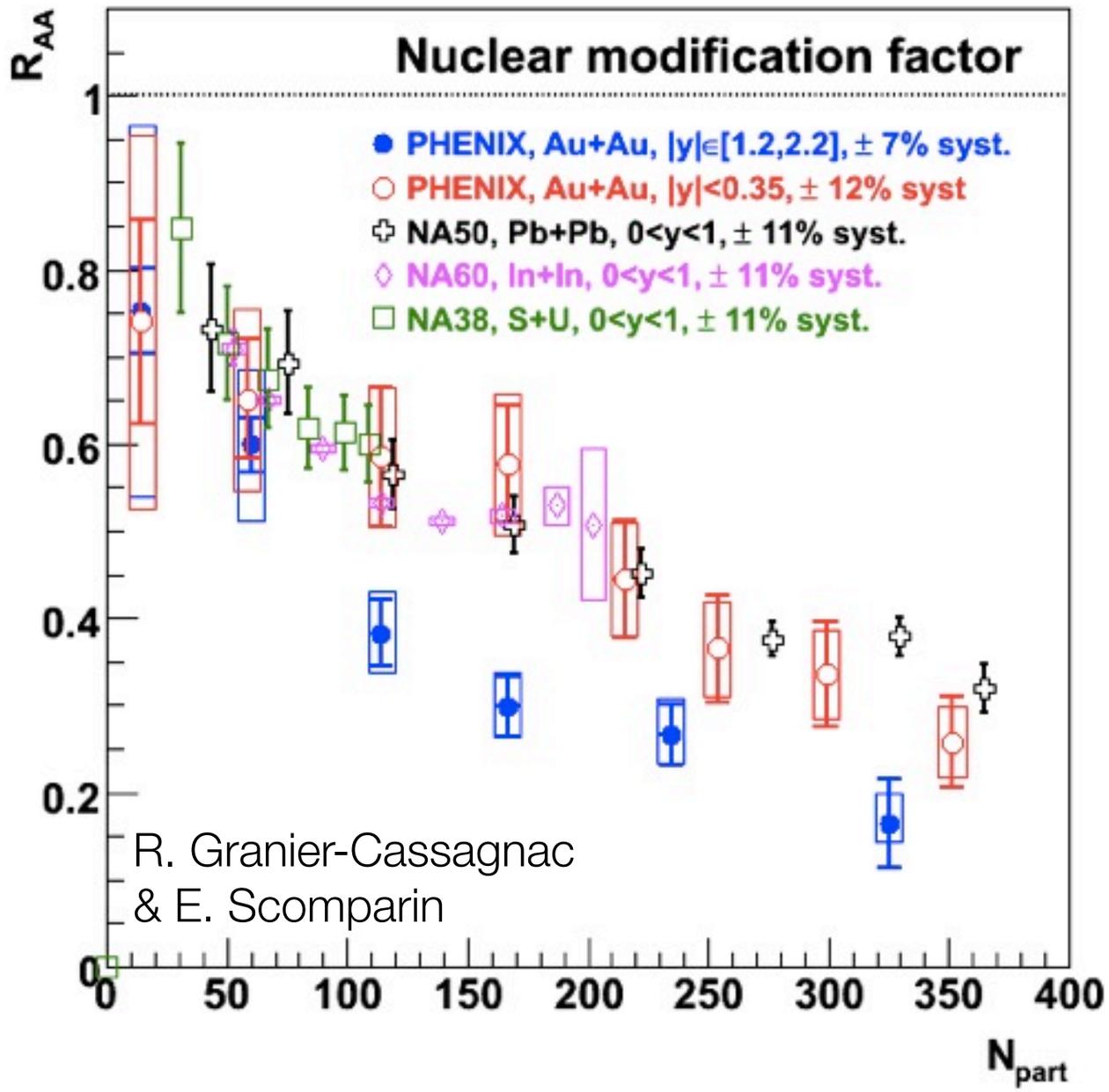
Heavy Ion Collision Event with 2 Jets

Integrated luminosity



9.7 μb^{-1} delivered, 9.2 μb^{-1} recorded by ATLAS

J/ψ suppression



Mocsy & Petreczky (2007)

state	χ_c	ψ'	J/ψ	Υ'	χ_b	Υ
T_{dis}	$\leq T_c$	$\leq T_c$	$1.2T_c$	$1.2T_c$	$1.3T_c$	$2T_c$

Color screening predicts quarkonia states to melt at different temperatures,

At high densities, also expect some J/ψ regeneration (at low p_T)

Suppression factor observed to drop by ~2 between peripheral and central events:
similar over x10 in $\sqrt{s_{NN}}$

Run 169226, Event 379791
Time 2010-11-16 02:53:54 CET

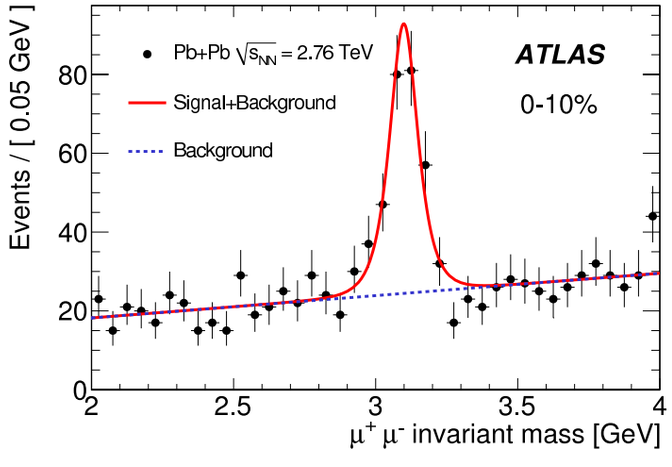
ATLAS EXPERIMENT

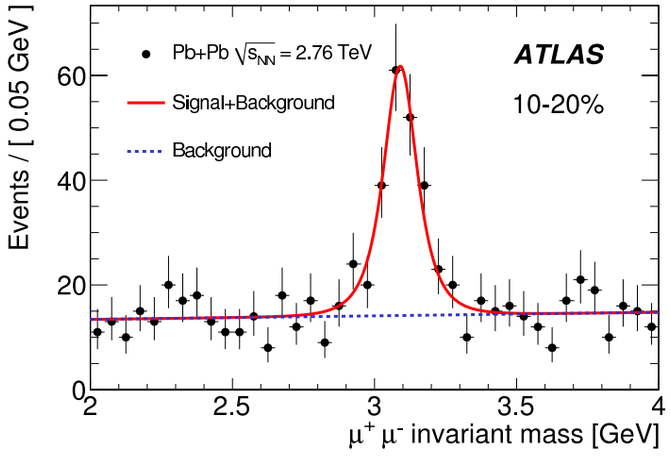
muon tracks
measured in
inner detector &
muon spectrometer

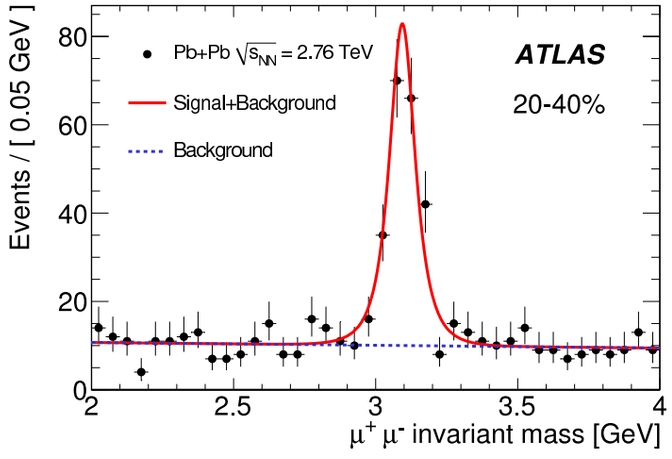
J/ψ candidate

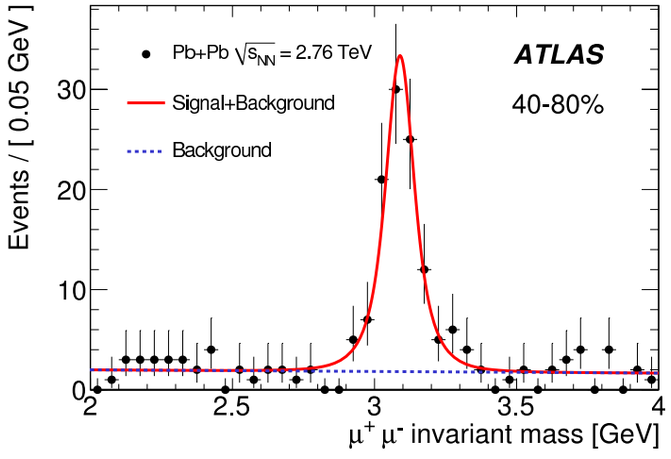
Signal extraction & uncertainties

- **Use pairs of opposite sign muons with cuts:**
  - $|\eta|<2.5$, $p_T>3$ GeV
- **Yield extraction based on sideband subtraction**
  - [2.95-3.25] GeV center
  - [2.4-2.8], [3.4-3.8] GeV sidebands
- **Cross check with unbinned maximum likelihood fit, with mass resolution as free parameter**









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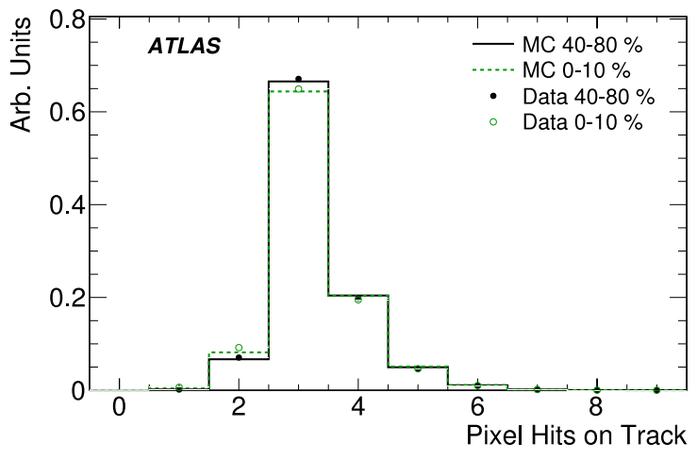
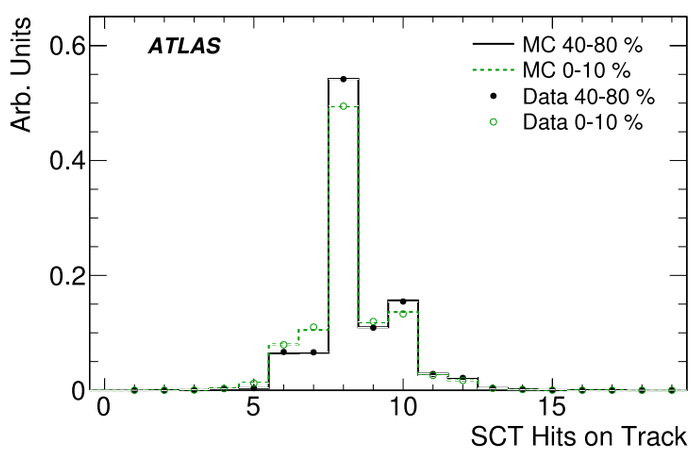
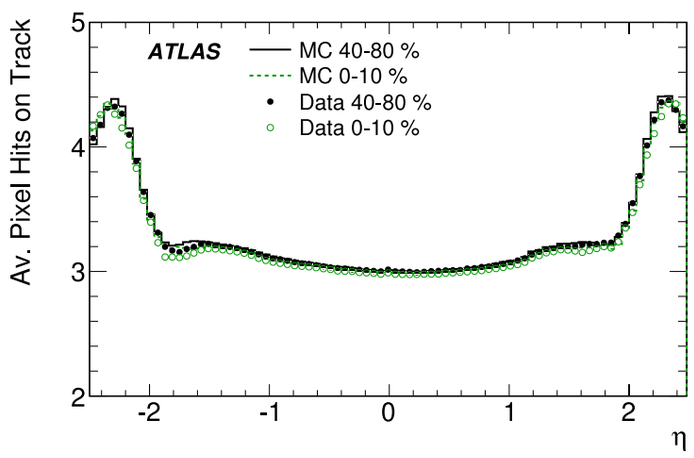
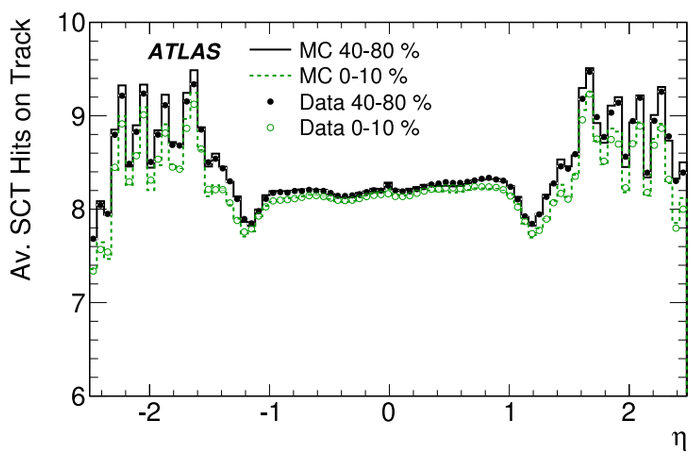
Tracking systematics

- **Efficiency varies with collision centrality**
  - up to 8% between central and peripheral collisions
- **Systematic uncertainties estimated by detailed comparison of track properties vs. MC**
  - Tracks with <2 pixel hits
  - Tracks with <6 SCT hits
  - Tracks with >1 B-layer “hole”
  - Tracks with >1 SCT “hole”
- **Determined to be 1-3%, depending on centrality**



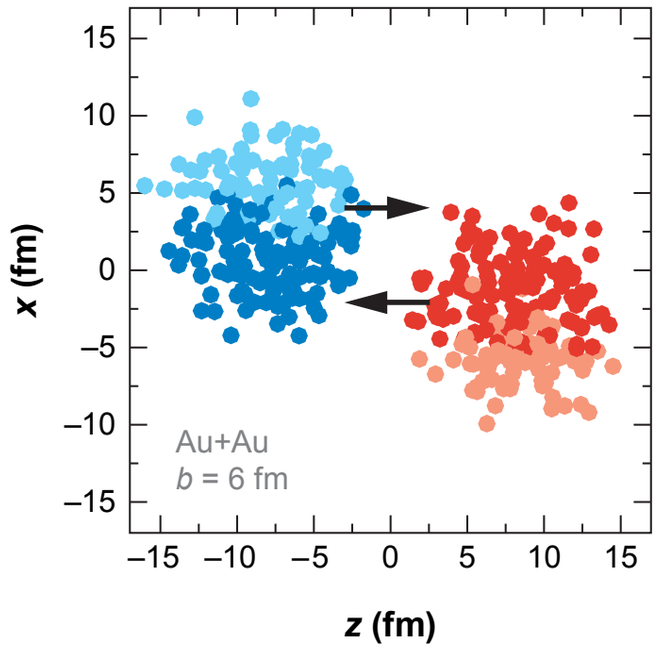




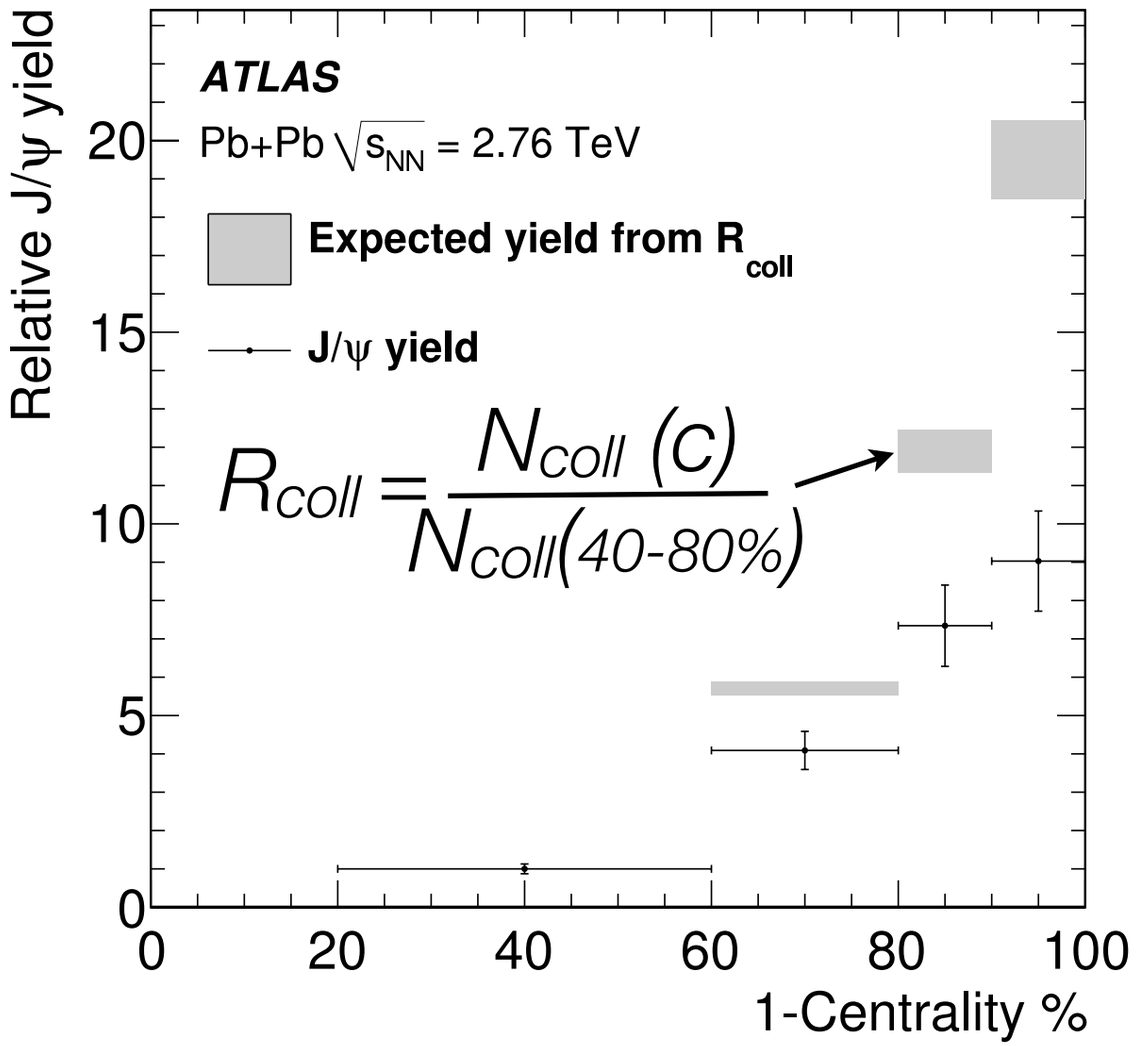


Yield ratios vs. Glauber predictions

- **Ratios of J/ψ yields compared to similar ratio calculated from Glauber calculation**



- **Using simple nuclear geometry to predict rates assuming yield scales with binary collisions**
  - Main uncertainty is fraction of total cross section *f*=98±1% after stringent selection cuts



Systematic shortfall vs. centrality!

J/ψ Yields

Centrality	$N^{\mathrm{meas}}(J/\psi)$	$\epsilon(J/\psi)_c/\epsilon(J/\psi)_{40-80}$	Systematic Uncertainty		
			Reco. eff.	Sig. extr.	Total
0-10%	190 ± 20	0.93 ± 0.01	6.8 %	5.2 %	8.6 %
10-20%	152 ± 16	0.91 ± 0.02	5.3 %	6.5 %	8.4 %
20-40%	180 ± 16	0.97 ± 0.01	3.3 %	6.8 %	7.5 %
40-80%	91 ± 10	1	2.3 %	5.6 %	6.1 %

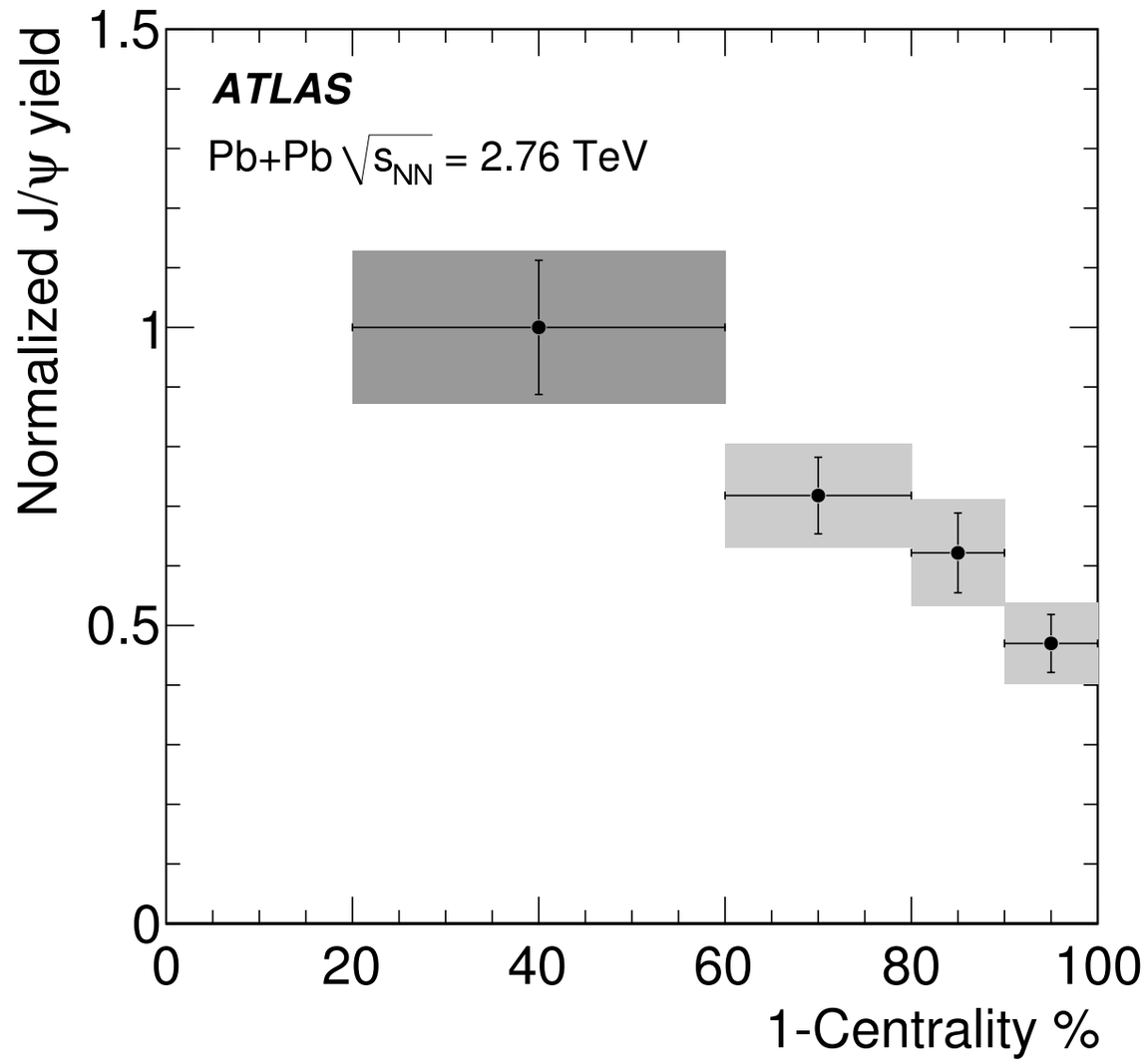
Yields within kinematic acceptance: $|\eta_\mu|<2.5$, $p_{T,\mu}>3$ GeV

Absolute efficiency not used since defined as a ratio relative to the most peripheral bin (40-80% here)

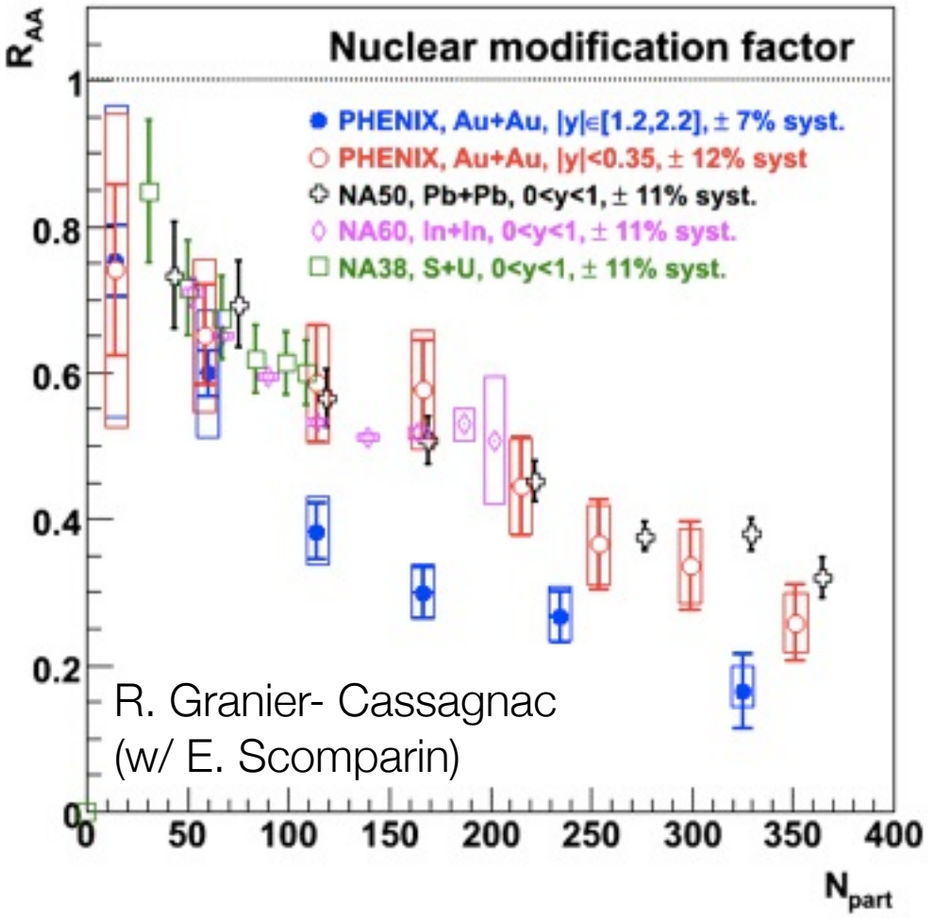
Statistical error on efficiency ratio from finite MC statistics

Suppression of J/ψ Phys Lett. B697 294-312

- **Dividing yield ratio by ratio of binary collisions gives the "normalized" yield**
  - Similar to "R_{CP}" in heavy ion literature (ratio of central to peripheral)
- **All ratios and errors scaled by measured yield in 40-80%**
  - Statistical & systematic errors not fully propagated

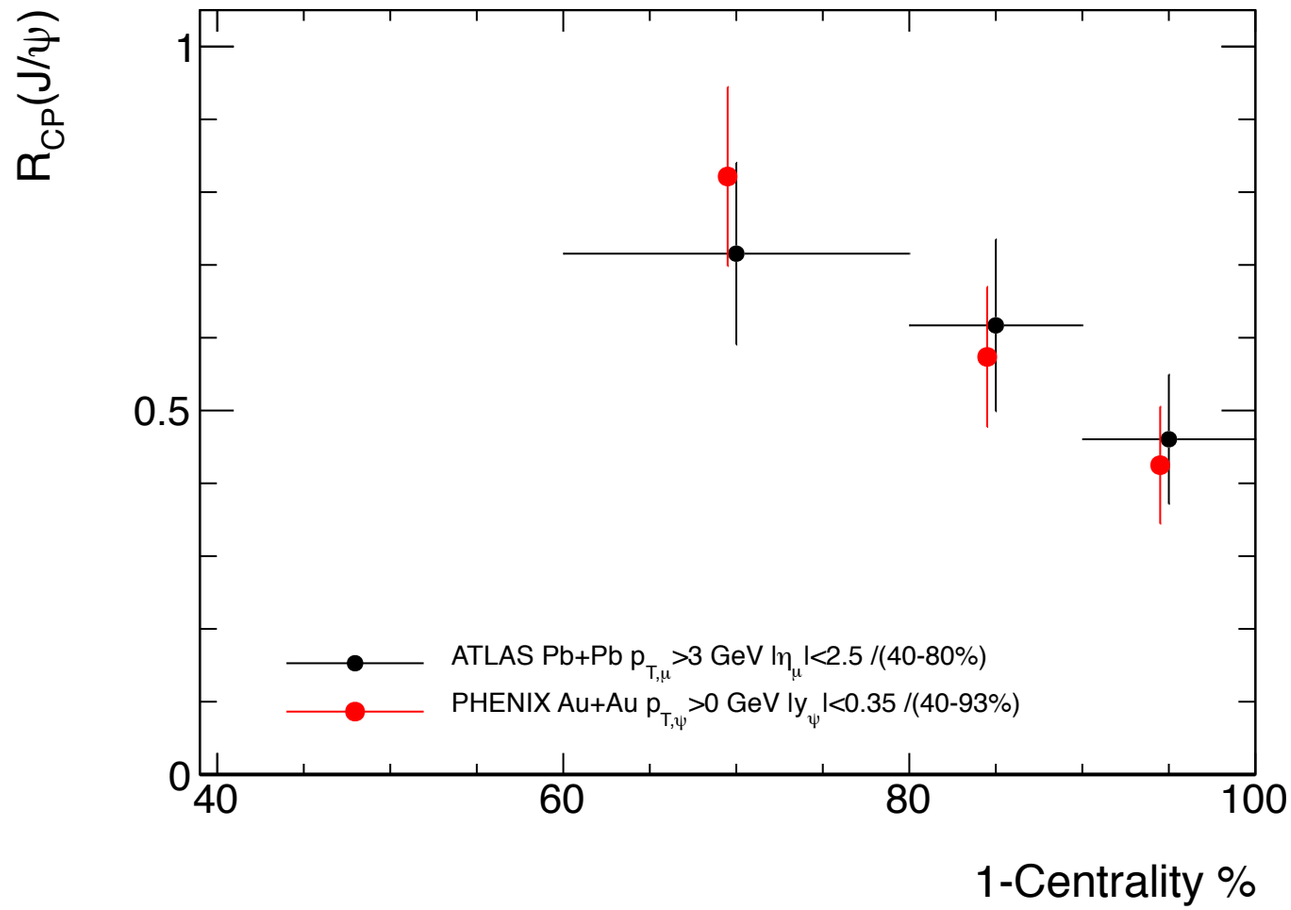


Comparison with lower energy data



see also J. Nagle, http://arXiv.org/abs/nucl-ex/0509024v1

PAS & J. Jia - replotted from public data



PHENIX data on R_{AA} (relative to p+p) recombined and ratios taken w.r.t. 40-93% bin, errors include uncorrelated & estimate of N_{coll} errors

Centrality dependence of suppression appears invariant with beam energy

Comments on ATLAS vs. PHENIX

- **Intriguing that the ATLAS & PHENIX centrality dependence is so similar despite**
  - Different CM energy (x14 between RHIC and LHC energies)
  - Different initial energy density (x3 estimated by ALICE - lower bound)
  - Different kinematic ranges (p_T>0 GeV for PHENIX, p_T > 6.5 GeV for ATLAS)
  - No correction for B feed-down (4% at PHENIX, 20% for ATLAS - estimate from CMS p+p J/ψ paper), and no accounting for charm feeddown.

Thanks to J. Nagle for references!

- **Many moving parts**
  - Should J/ψ suppression be affected by slowing of c and cbar?
  - Should the J/ψ's from B's be suppressed by b quenching?
  - Regeneration might be an issue, but probably not at the p_T range measured by ATLAS
- **Given this, the energy independence of suppression (from NA50 to ATLAS) seems difficult to achieve by a simple density dependence**

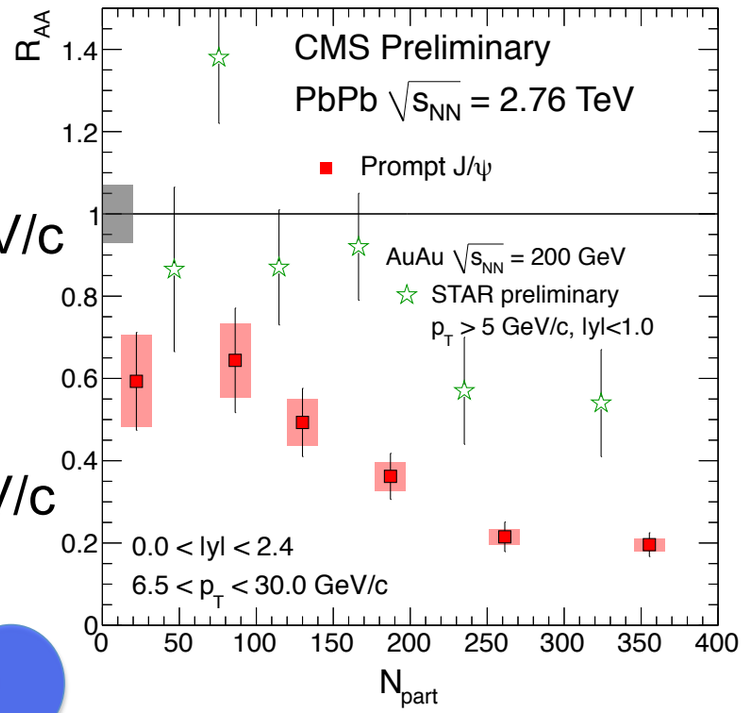
ATLAS vs. CMS

J/ψ R_{AA} vs. N_{part} Comparison

CMS
$p_T^{J/\psi} > 6.5$ GeV/c

STAR
$5 < p_T^{J/\psi} < 8$ GeV/c

Z. Tang (Mon.)



40-80%

Compatible with ATLAS

R_{cp}= 0.5 ± 0.2

Phys.Lett.B697: 294-312,2011

P. Steinberg (Mon.)
R. Sandstrom (Thur.)

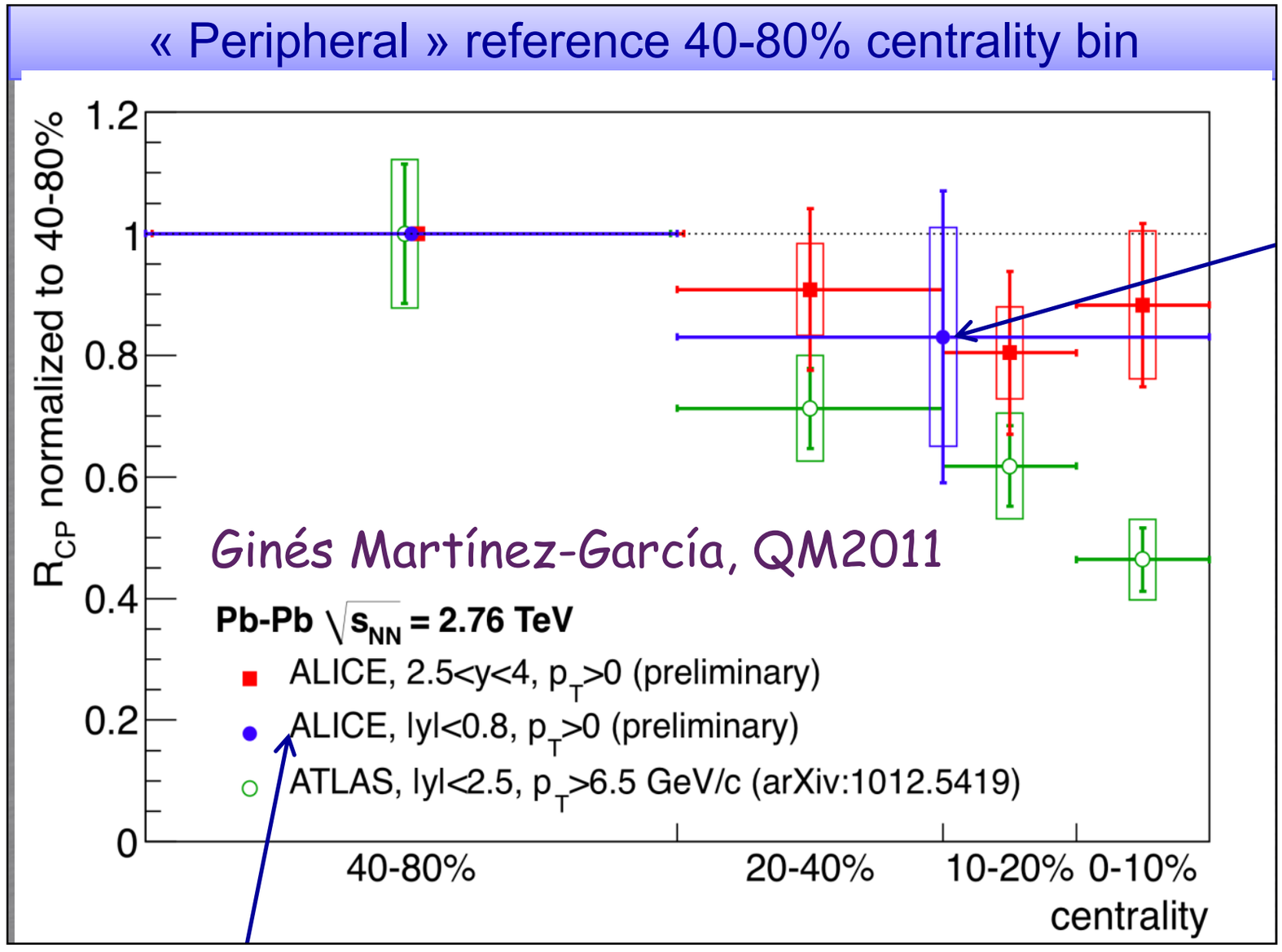
more like 0.5±0.1...

STAR $\sqrt{s}$=200 GeV, J/ψ $5 < p_T < 8$ GeV/c

Stronger suppression seen in CMS than at STAR

CMS sees a R_{cp}~1/3 for prompt, so we are broadly compatible, but clearly requires a direct check!

ATLAS vs. ALICE



~Orthogonal p_T and **η** ranges,
but very different centrality dependence!

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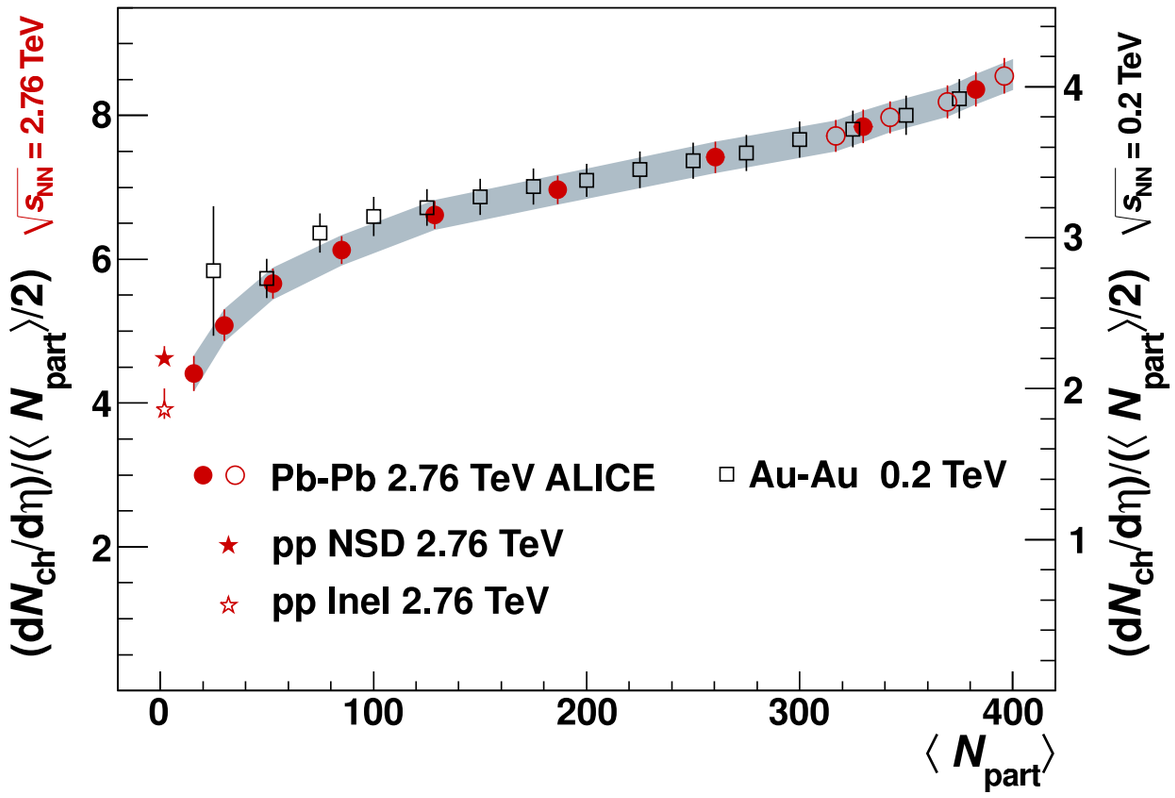
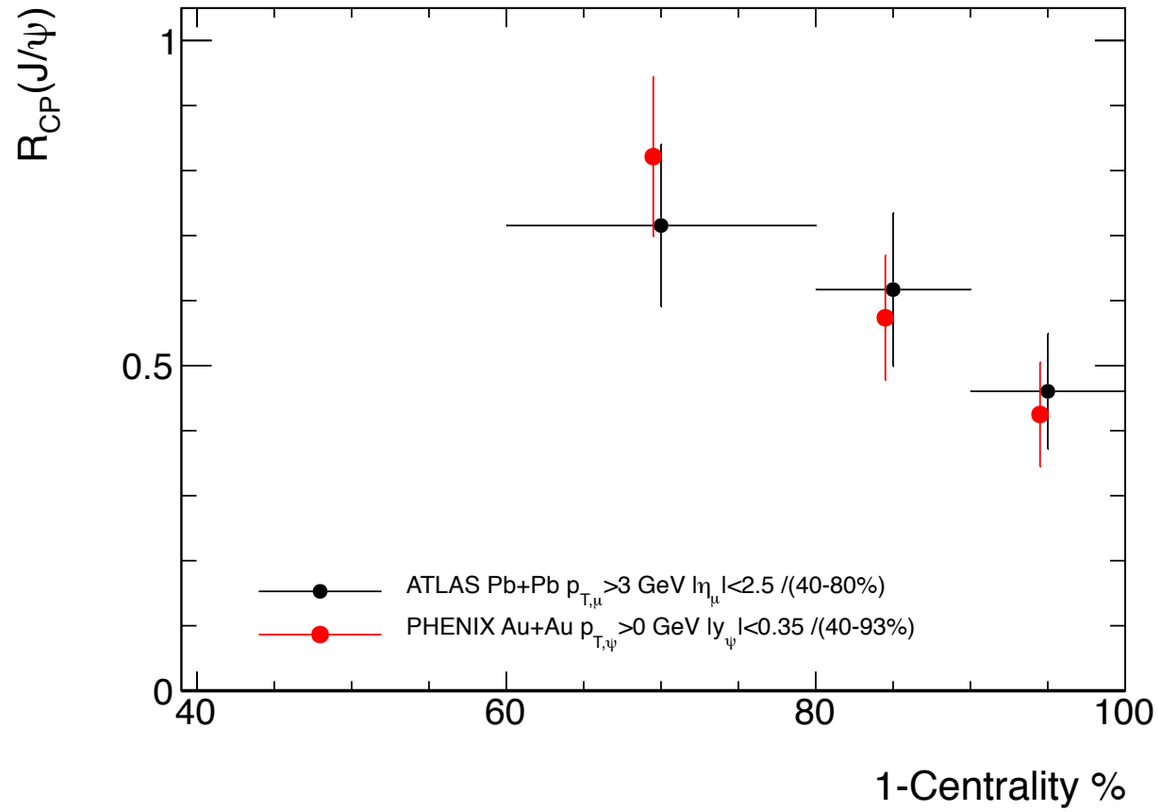
Connection or coincidence? Some observations





"R_{CP}" scales for:

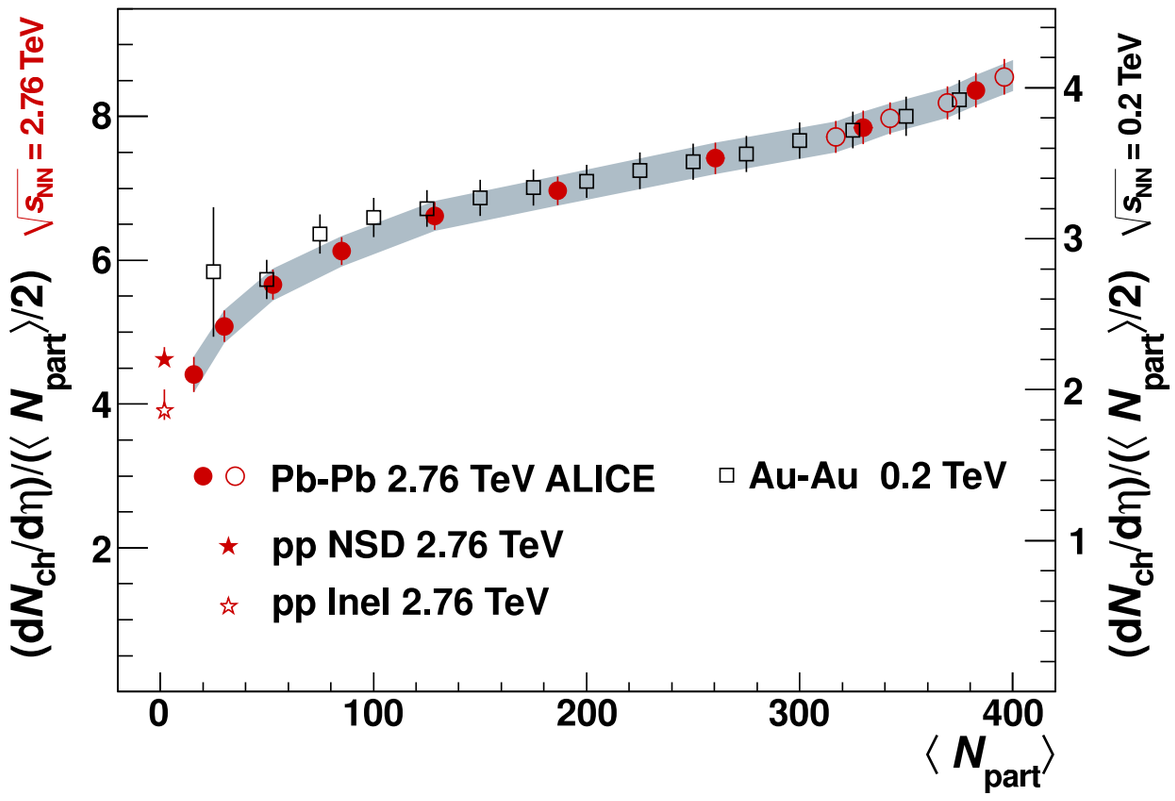
1. inclusive yields (ALICE vs. RHIC, N_{part})
2. J/ψ (ATLAS vs. PHENIX, N_{coll})

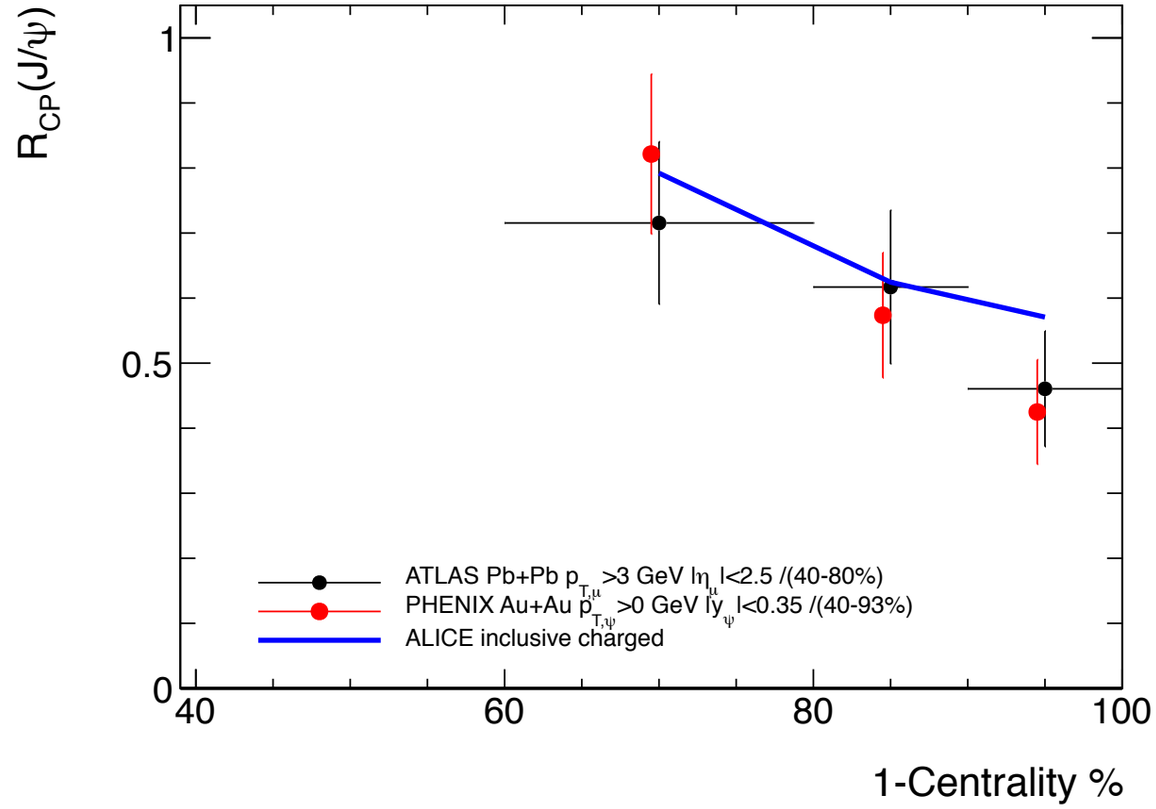
$$R_{CP}^{p,c} = \frac{N_C}{N_P}\frac{N_{coll,part}^P}{N_{coll,part}^C}$$

Can change from N_{part} to N_{coll}, do results still ~scale?

J/ψ's behave similar to inclusive hadrons (not the first time)

Connection or coincidence? Some observations





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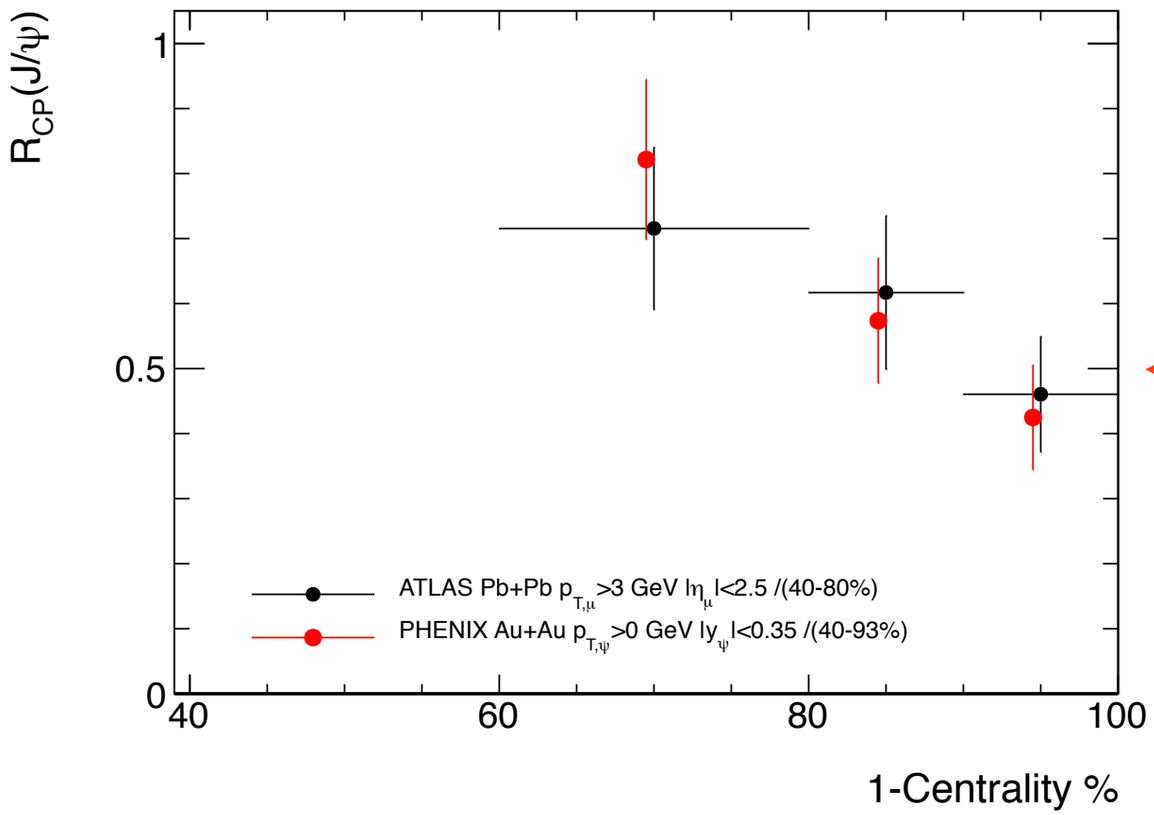
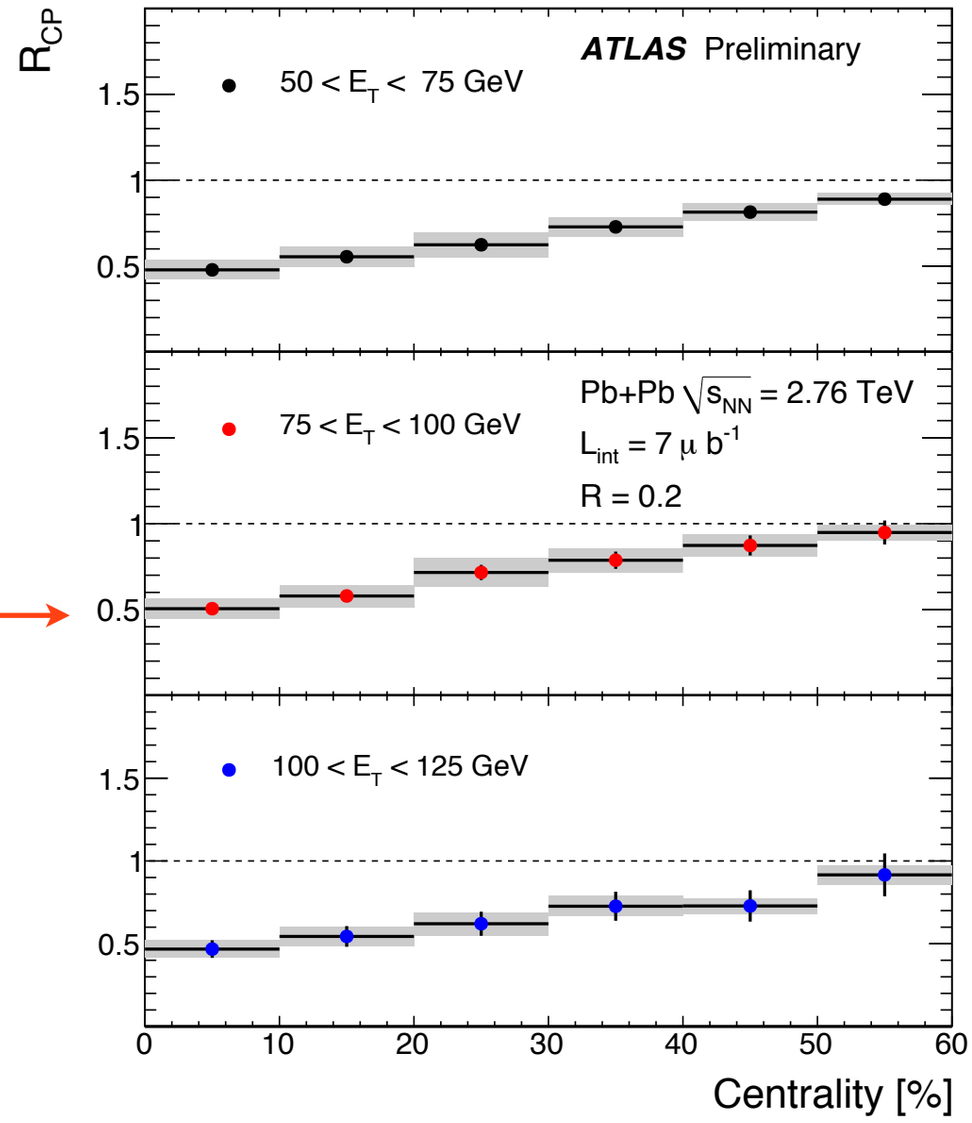




Suppression of high p_T J/ψ similar to that seen for inclusive jets

ATLAS EXPERIMENT

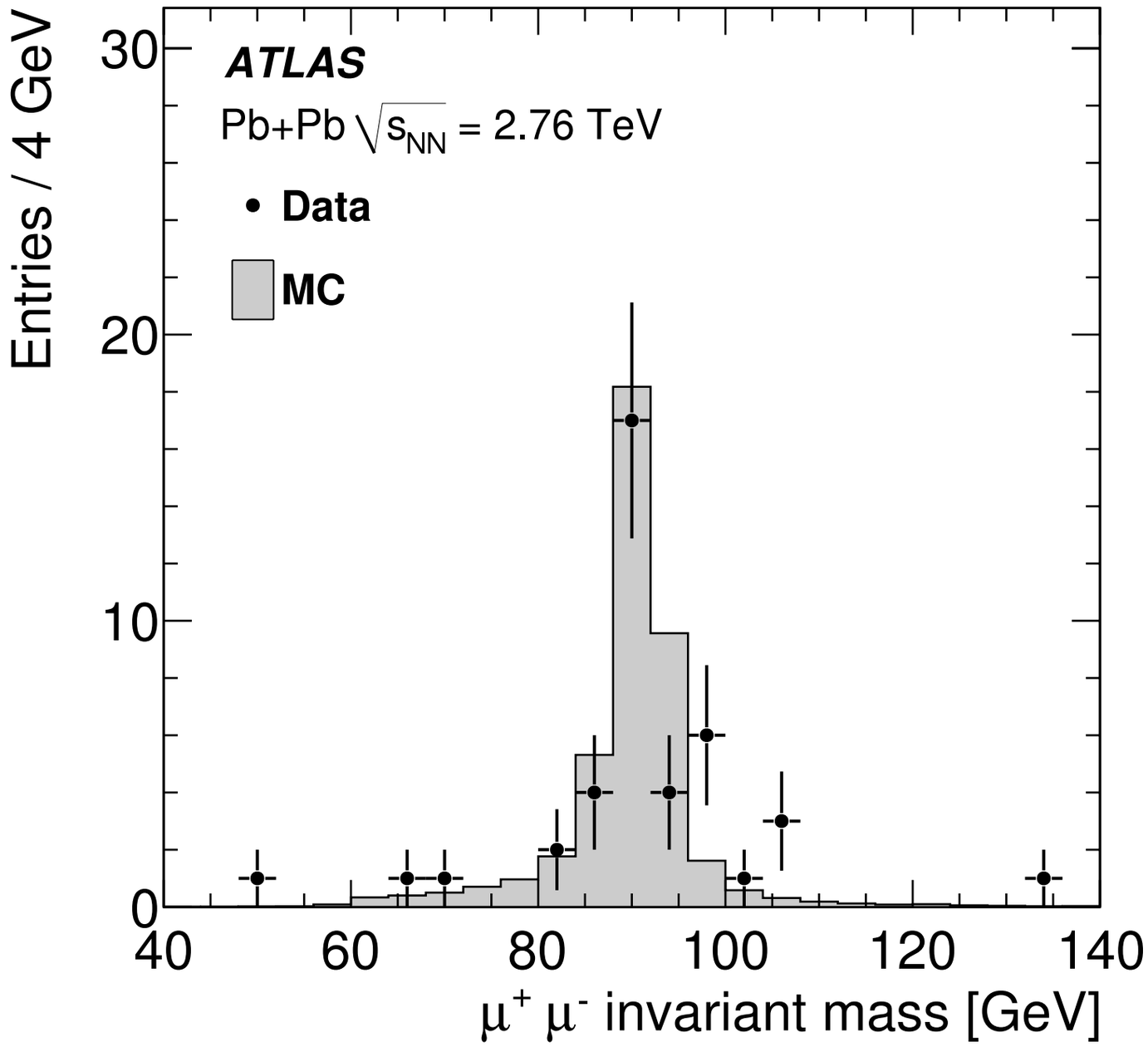
Run 169045, Event 728772

Time 2010-11-12 01:52:11 CET

Heavy Ion Collision with a Z→μμ Candidate

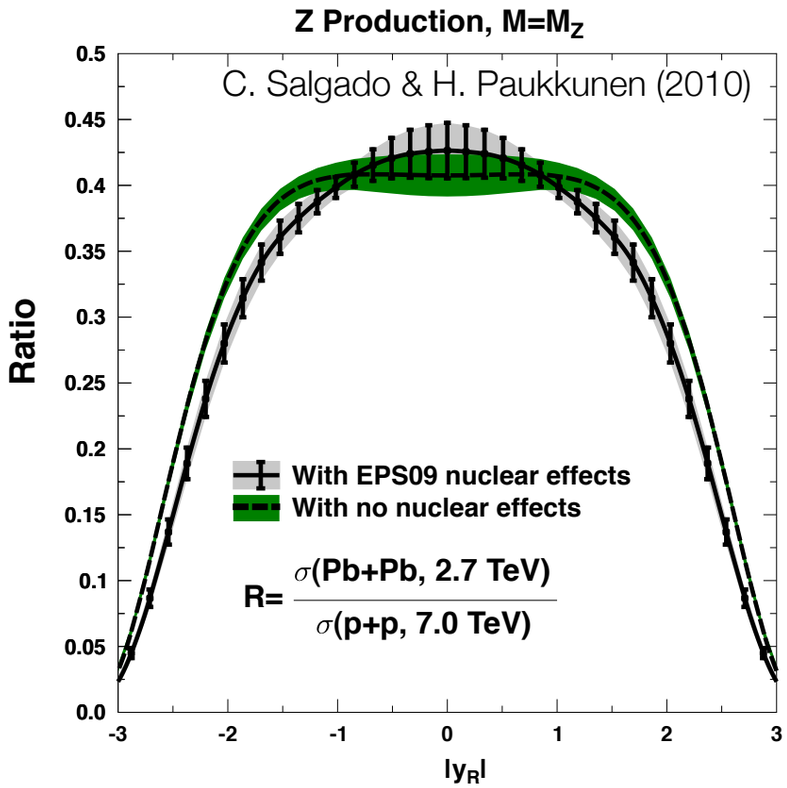
Z reconstruction in heavy ion collisions

- **Muon cuts for opposite sign pairs:**
  - $|\eta|<2.5$, $p_T>20$ GeV
  - $|\eta_1+\eta_2|>0.01$ to reject cosmic ray muons
  - [66,116] GeV mass window
- **Relative yield calculation similar to J/ψ**
  - All systematics have been assumed to be the same as with J/ψ
  - Conservative assumptions
- **38 Z candidates found**

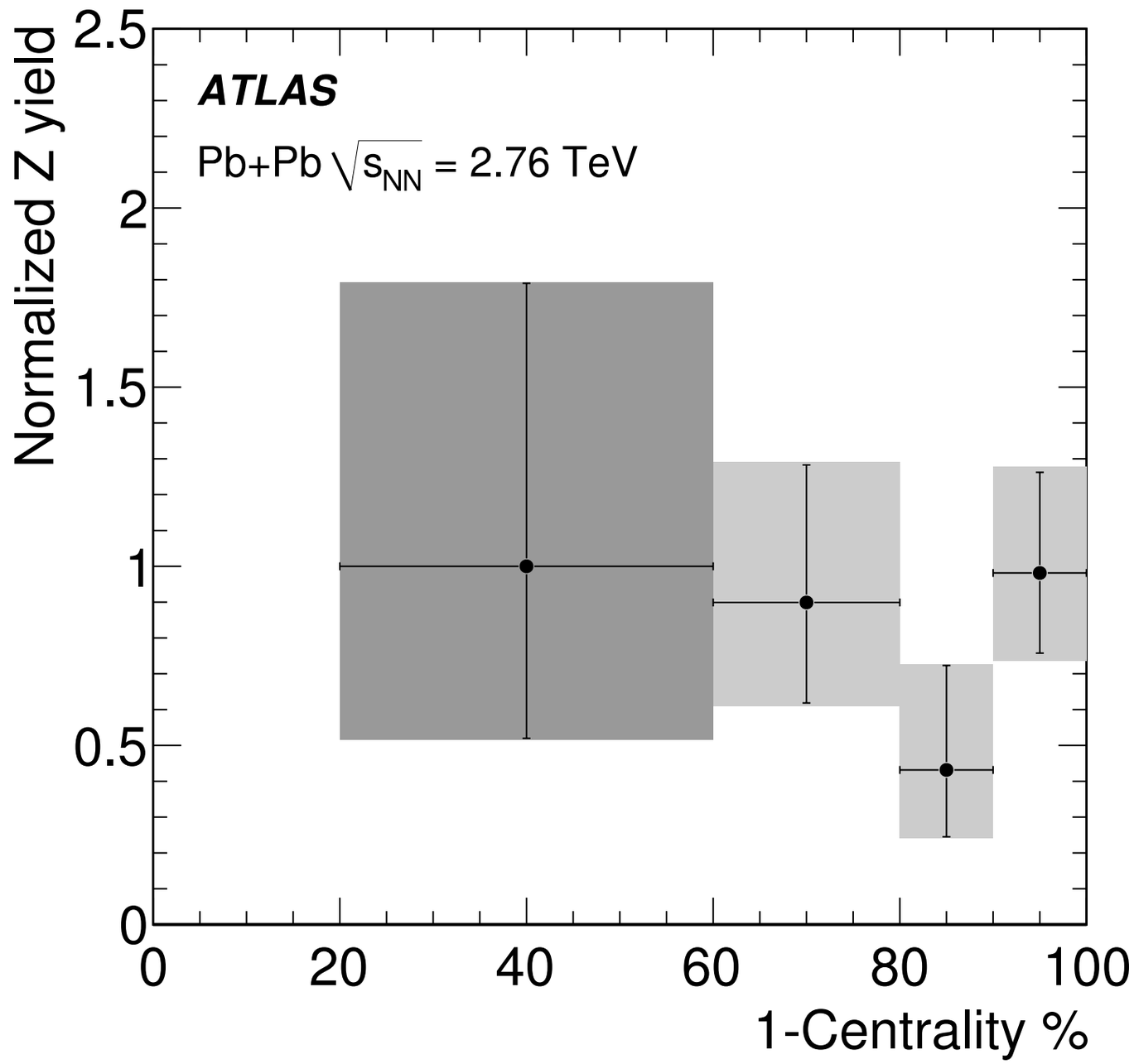


Z centrality dependence

- **Z's are not expected to be suppressed, but might be affected by shadowing**



- **Recent calculations show little effect from this**
- **Statistics too low for any quantitative statements.**



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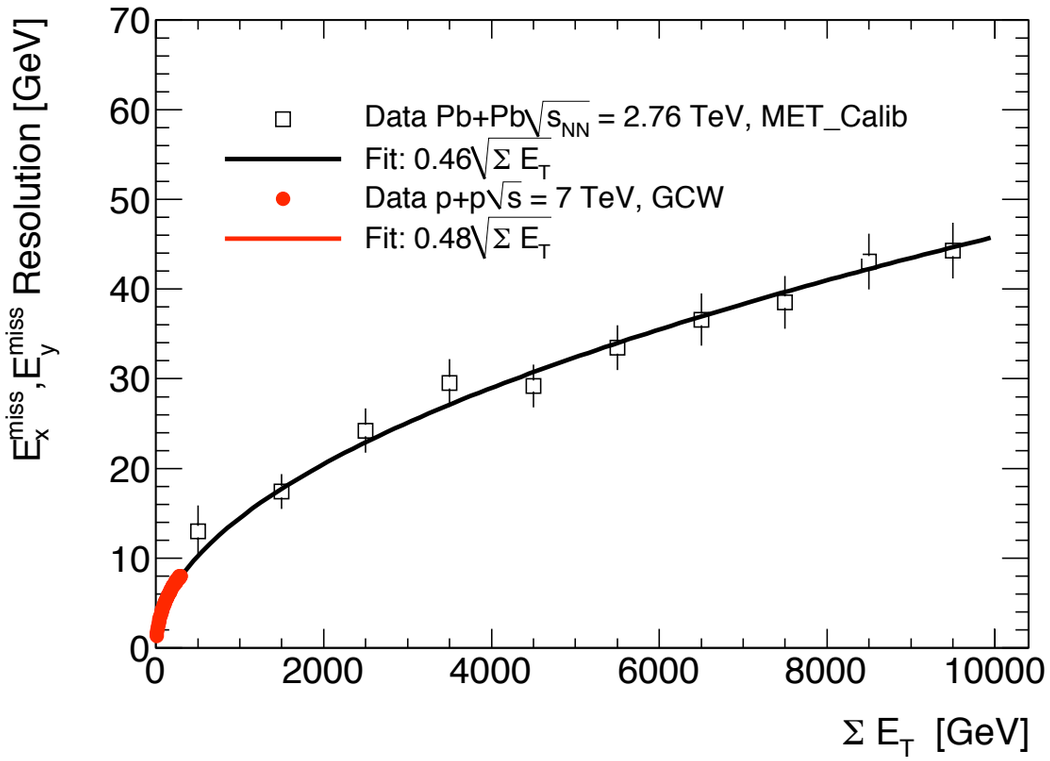
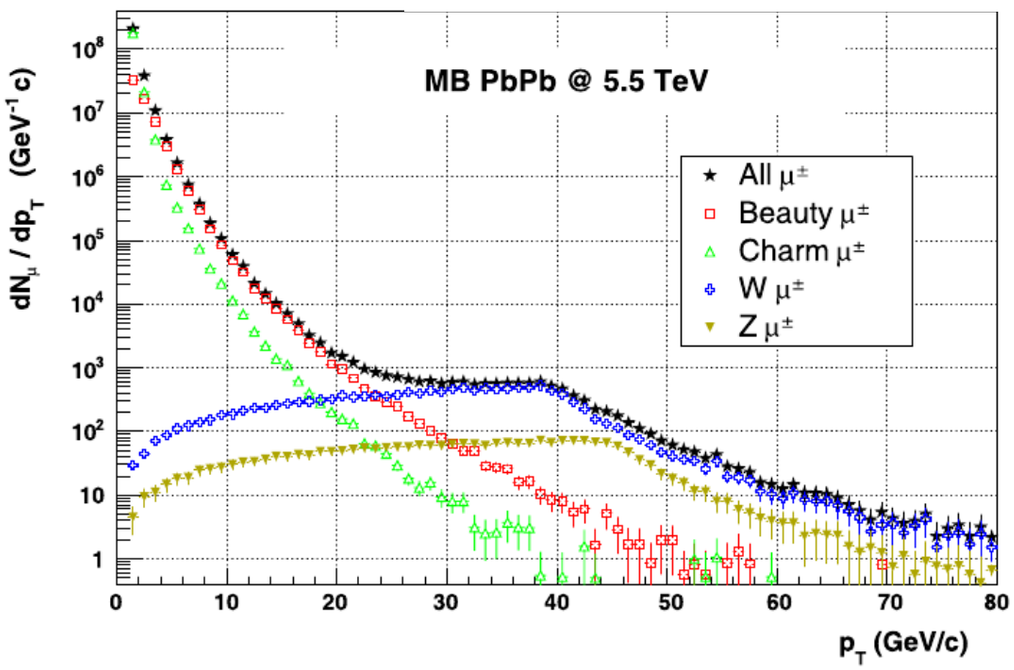
Extracting W in HI collisions

In ATLAS, missing energy scales with the total energy (like p+p!)
In central events you can get large missing E_T



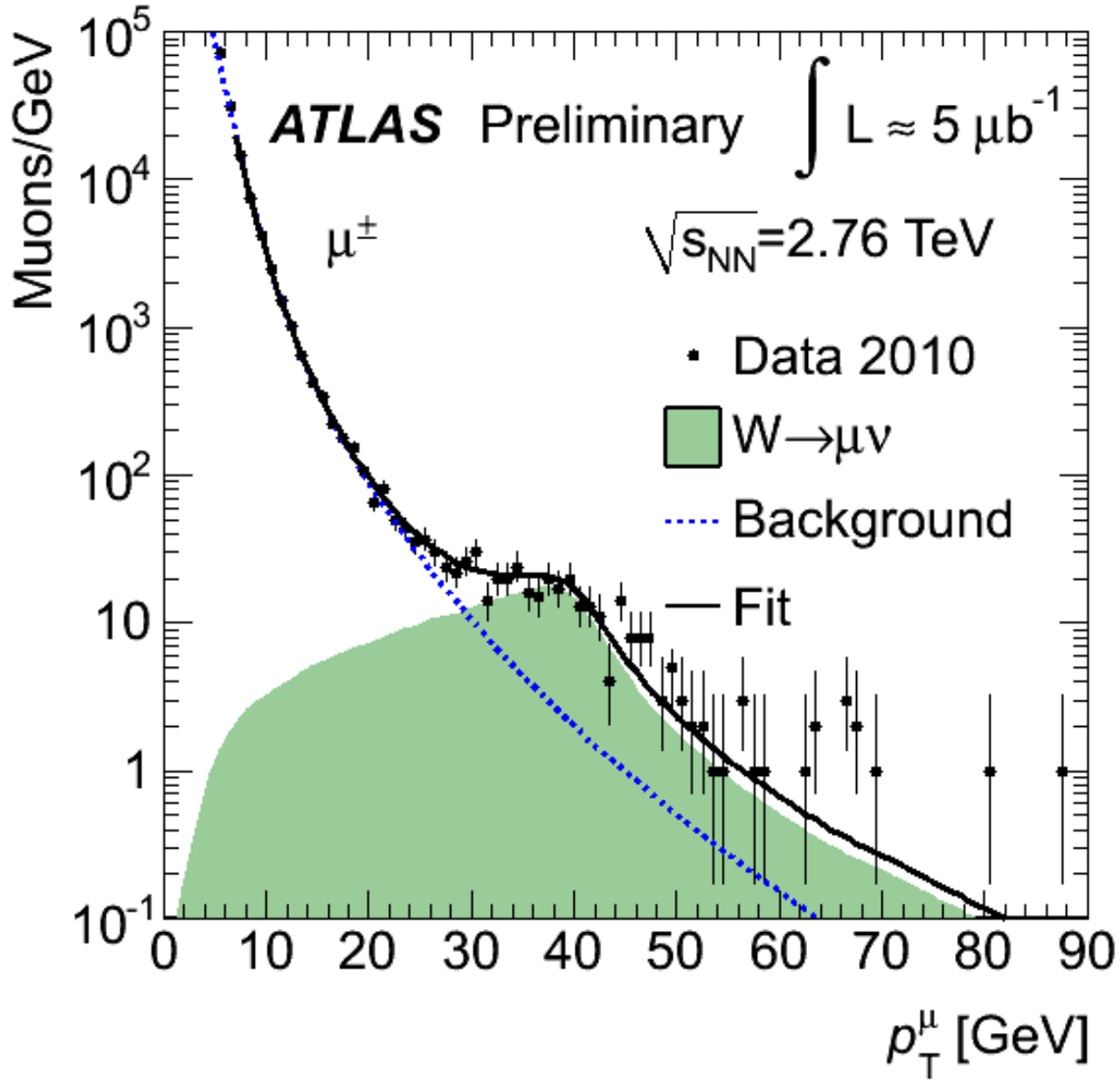
Eur. Phys J. C 49, 149-154 (2007)



More straightforward to measure the shoulder from the muons from W decay, dominates spectrum above ~30 GeV

Extracting W yields in HI collisions

- **With 2/3 statistics, a very clear signature of W's!**
- **Analysis procedure:**
  - Remove muons from Z decays
  - Veto decays in flight
  - Generate template from W decays in 2.76 TeV p+p MC
  - Fit a function to describe background (primarily heavy flavor)
  - Unbinned fit combining background fit plus W template



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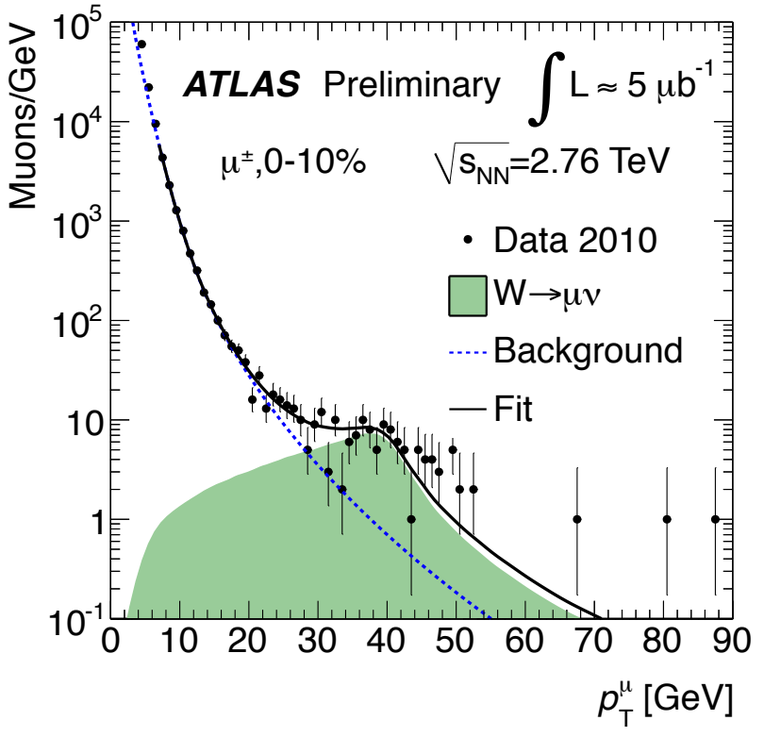
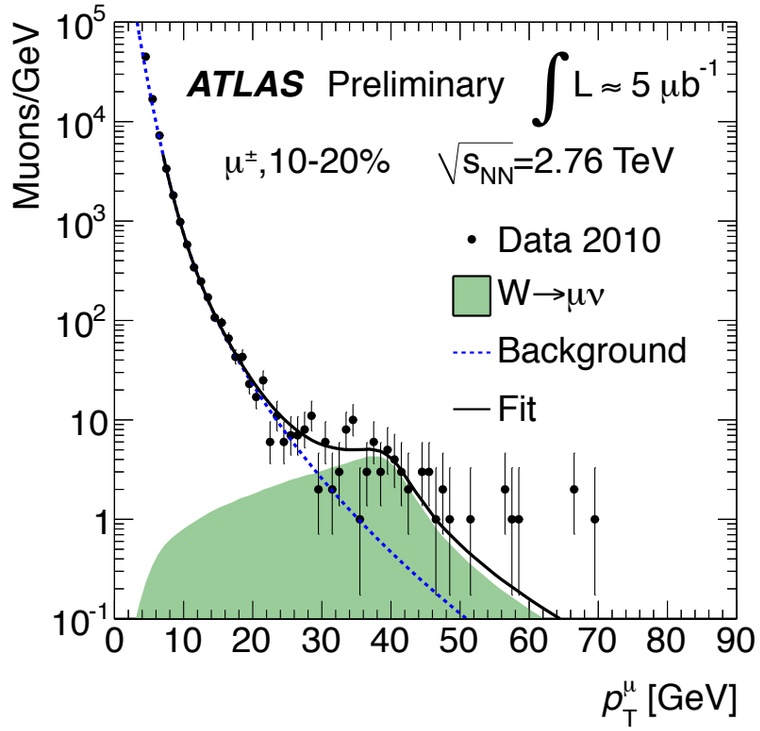
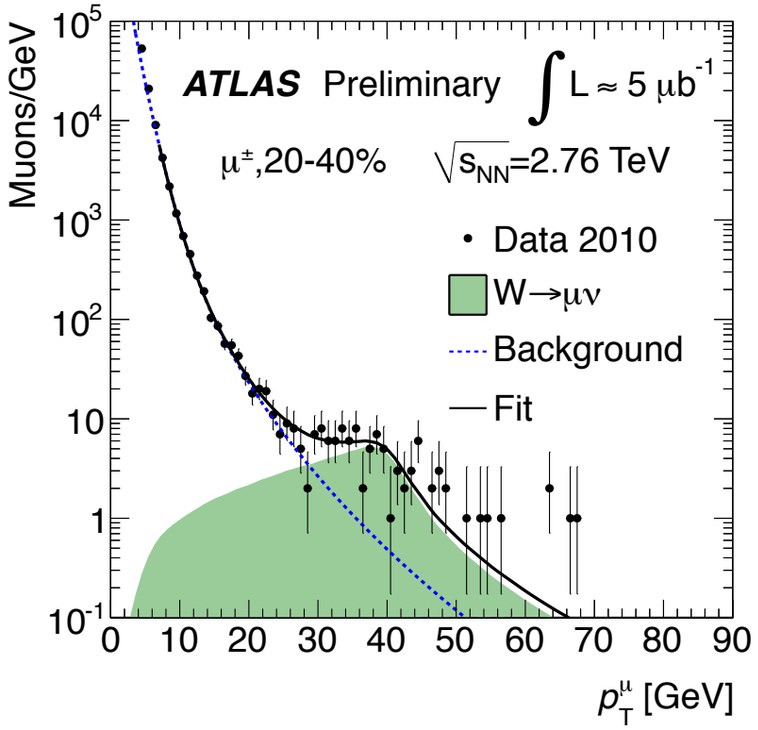
Yield extraction in centrality bins

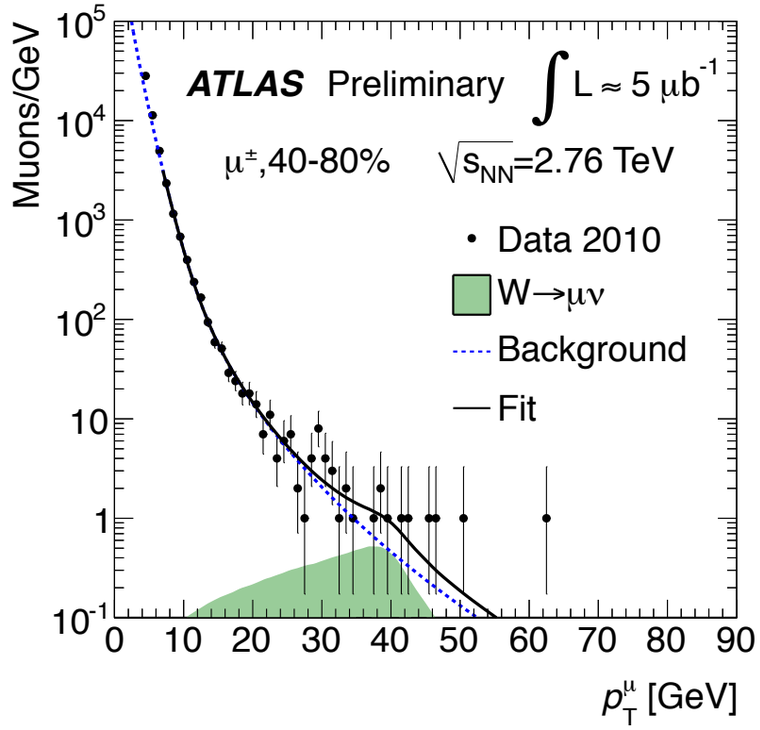
- **Fits performed vs collision centrality, with background fit redone for each bin (in case HF spectrum is modified)**
- **Good statistics except in peripheral bin**

Centrality	N_W^{fit}
40-80%	12^{+13}_{-12}
20-40%	118^{+17}_{-24}
10-20%	97^{+16}_{-18}
0-10%	165^{+23}_{-25}
W (all)	399^{+36}_{-38}



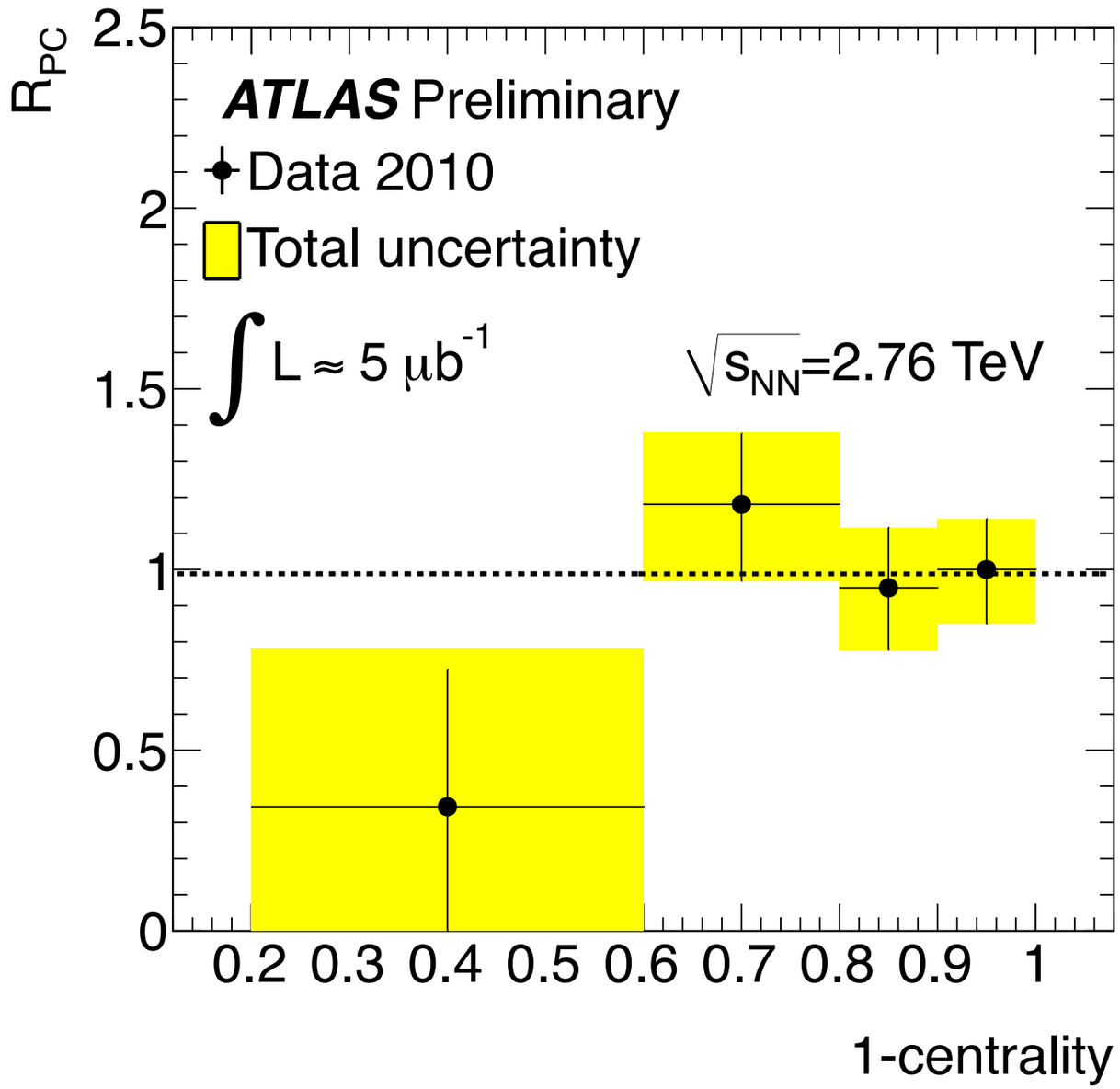






Centrality dependence of W yields

- **Centrality dependence pinned on central data rather than peripheral**
  - R_{PC} vs. R_{CP}
- **Fit to a flat line gives unity, with good χ^2**
- **Consistent with binary collision scaling**



Charge dependence

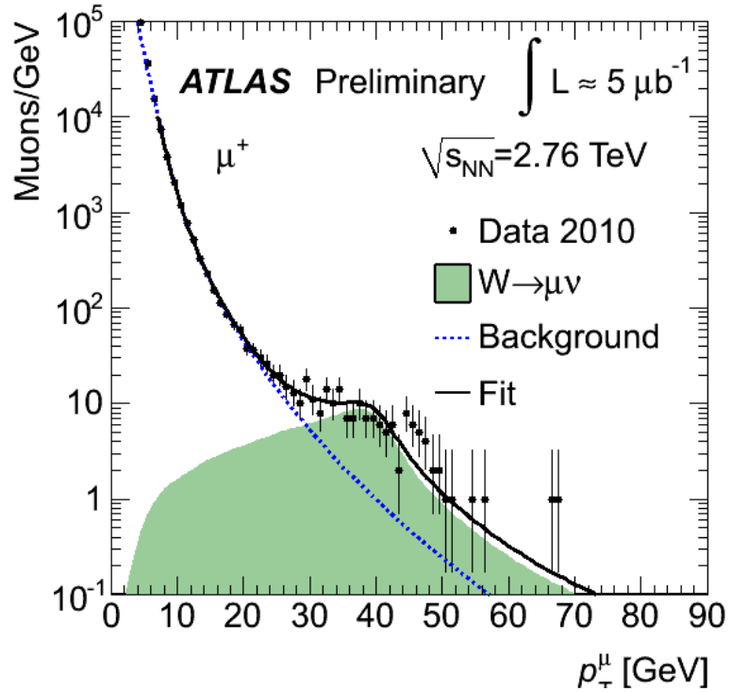
- **d/u asymmetry from n/p ratio implies more W- than W+**

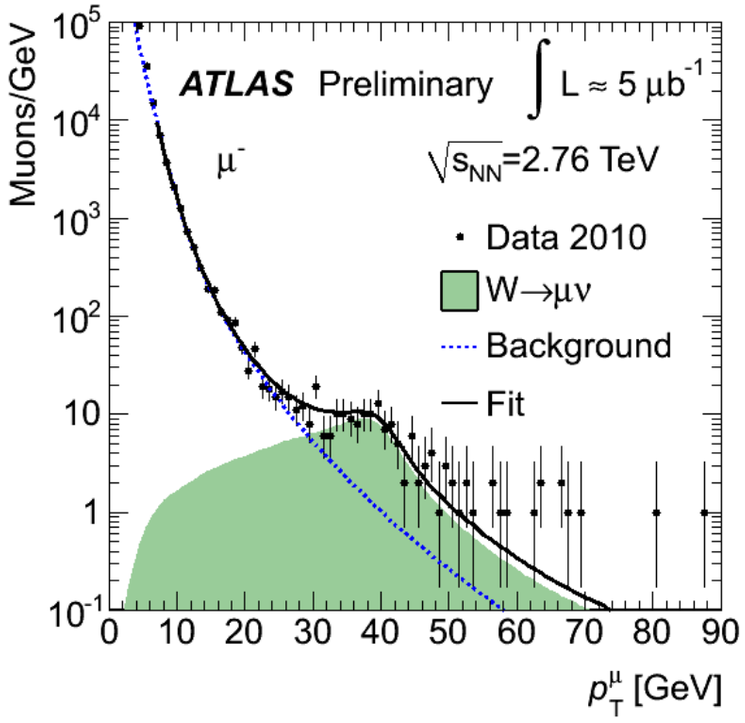
- **Theory (Paukunnen & Salgado) predict 0.90±0.04 for Pb+Pb**
  - No nuclear modification assumed
  - pp gives 1.65 and nn gives 0.62 from NNLO QCD + MSTW2008

- **We observe**

$$R_{W^+/W^-} = \frac{198^{+25}_{-26}}{204^{+27}_{-31}} = 0.97^{+0.18}_{-0.19}$$

- **Nothing anomalous but requires higher statistics**





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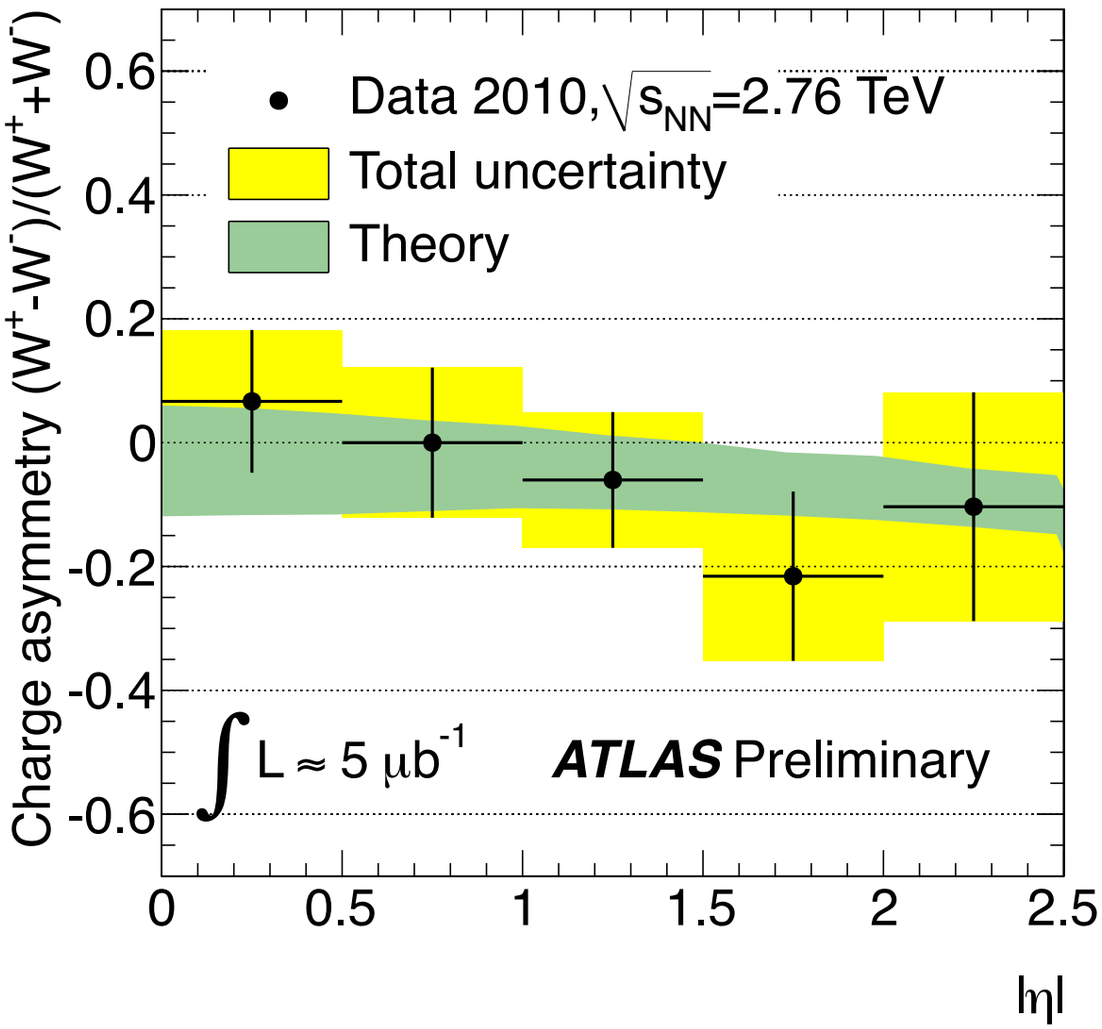
W^-	204^{+27}_{-31}
W^+	198^{+25}_{-26}
W (all)	399^{+36}_{-38}

Muon charge asymmetry

- **Precision asymmetry measurement gives information on nPDFs**
- **First attempt with existing statistics for p_T>30 GeV**
  - Background from b-bbar contributes at 19% level, included as systematic error
- **Theory curve from Paukunnen and Salgado, including nPDF**
- **No asymmetry observed within statistical errors**
  - Measurement will improve with increasing luminosity



$$A_\mu = \frac{d\sigma_{W_{\mu^+}}/d\eta - d\sigma_{W_{\mu^-}}/d\eta}{d\sigma_{W_{\mu^+}}/d\eta + d\sigma_{W_{\mu^-}}/d\eta}$$

W/Z ratio

- **Useful test of the standard model and PDFs**
- **Corrections for acceptance and efficiency taken from MC**
- **Predictions**
  - SM prediction for Pb+Pb: $R_{W/Z}$ = 11.5 ± 0.7 – no effects from nPDFs
  - p+p: $R_{W/Z}$ = 11.3 ± 0.6
  - n+n: $R_{W/Z}$ = 10.8 ± 0.6
- **We measure: $R_{W/Z}$ = 10.5 ± 2.3**
  - Good agreement with standard model prediction

Conclusions

- **Measurements of J/ψ, Z and W**
- **No separation of prompt and non-prompt J/ψ yet**
  - In plan for next iteration on 2010 data
- **Without this, still see a clear suppression of factor of 2 relative to peripheral events**
  - Similar to lower energy HI data (albeit at low pT)
  - Similar to our jet rates
- **Vector bosons also measured**
  - W centrality dependence shows binary collision scaling
  - Z statistics preclude any strong statements
  - W^+/W^- and W/Z ratios consistent with SM
- **Looking forward to 5x increase in luminosity in 2011!**